The Open University

S103 TVN

S103 discovering science

Notes for television programmes

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The science of climate

We recommend that you watch this programme after you have completed studying Block 2. You should read the following notes before watching the programme.

The programme concentrates on two of the main themes of Block 2 'A temperate Earth', namely:

- the evidence that the Earth's climate, and in particular the global mean surface temperature, has changed throughout Earth history;
- the possible causes of these changes.

Some of the evidence for climate change presented here is discussed in the book and some is not, so the book and the television programme complement each other. In exploring possible causes of climate change, the programme includes most of those outlined in Section 9 of Block 2, and also looks at how well climate models can account for climate change over the past 100 years or so.

As you watch the programme, make a note of the sources of evidence for climate change that are mentioned, and also note what is said about the interplay between measurements, models, theories and predictions. There are two questions below to answer after watching the programme, and you will find it helpful to read these beforehand.

As you watch the programme make a note of points that will enable you to answer the following questions.

Question 1

(a) List the different types of evidence for climate change that are mentioned in the programme.

(b) Two of these types of evidence are not discussed in Block 2. For each of them, describe how scientists use them to deduce that the climate has changed, and state for how far into the past the evidence can be used.

Question 2

One of the scientists in the programme says that a particular climate model initially predicted a greater increase in global mean surface temperature over the last 100 years than the temperature records indicate actually occurred. What additional factor was added to the model to improve the accuracy of its prediction, and how does this additional factor lead to a reduction in the temperature increase?

Note: You may have noticed that the animation of the changing shape of the Earth's orbit shows the Sun at the centre of the elliptical orbit. In fact, the Earth's elliptical orbit is offset, so that the Sun is not at the centre, as shown in Figure 9.6 of Block 2. For part of the orbit the Earth is closer to the Sun than when it is in the circular

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orbit, and for part of the orbit it is farther from the Sun than in the circular orbit.

The answers to these questions can be found at the end of this booklet.

A formidable foe

We recommend that you watch this programme after you have completed studying Block 4, Section 6. You should read the following notes before watching the programme.

This programme is about a disease that kills two million people a year — malaria. The disease is caused by a single-celled parasite, *Plasmodium falciparum*, which is a member of the kingdom Protoctista (Block 4, Section 4.3).

❑ Is *Plasmodium* a prokaryote or a eukaryote?

■ It is a eukaryote — all protoctists are eukaryotes (and most are unicellular; Block 4, Table 4.1).

The programme explores the life cycle of the malaria parasite and of the *Anopheles* mosquito, which transmits the parasite to humans. It also looks at the history and symptoms of malaria and at the efforts of various research teams to fight the disease.

As you watch the programme make a note of points that will enable you to answer the following questions. You will need to recall information from Block 4, particularly Sections 2, 3 and 6. The answers are not stated explicitly in the programme but you should be able to work them out.

Question 1

Which stages of the *Plasmodium* life cycle involve asexual reproduction and which involve sexual reproduction? Describe the stages of the life cycle.

Question 2

Draw a sketch of the life cycle that you described in Question 1, indicating where mitosis, meiosis and fertilization occur.

The answers to these questions can be found at the end of this booklet.

In the programme there is much discussion of the efforts being made to control malaria by attacking either the vector (i.e. the female *Anopheles* mosquito) or the parasite itself. The latter strategy involves attempts to develop protective or transmission-blocking vaccines. The scientists involved in this work are clearly concerned about the possibility of *Plasmodium* developing resistance to these vaccines. As you study Sections 9–11 of Block 4, think about the mechanisms by which resistance might be acquired.

A related TV programme, 'Sickle-cell disease: a lethal advantage', is designed be viewed towards the end of your study of Block 9, but you might find it interesting to view this programme straight after 'A formidable foe' too.

Sickle-cell disease: a lethal advantage

This programme is most relevant to Block 9 and you will be asked to view it as Activity 13.3 while you are studying that block. However, it is closely linked with 'A formidable foe', and it is transmitted early in the course so that you can view it while the latter programme is fresh in your mind. If you do this, you should read the following notes before watching the programme. When you view the programme while studying Block 9, you should refer to the notes for Activity 13.3 rather than these notes.

This programme is about human resistance to malaria, which is related to occurrence of an inherited disease, sickle-cell disease. As well as covering the biological cause of sickle-cell disease and its link with malaria, the programme also considers the social aspects of how sickle-cell disease affects the lives of the people who have it and how different communities, in the USA and Africa, are tackling the care of affected individuals. In addition, the programme stresses the evolutionary significance of the disease.

The programme 'A formidable foe' described the life history of the protoctist parasite, *Plasmodium falciparum*, that causes malaria. This has two hosts, mosquito and human, and is transferred between them by the mosquito feeding on the blood of humans. Removing the mosquito would annihilate the protoctist. The reproduction of the mosquito is so successful, however, that it has proved impossible to eradicate it, particularly in the tropics of Africa and southern Asia. Given the long history of malaria and the fact that it is the most prevalent of all serious diseases it is hardly surprising that humans have evolved mechanisms to 'strike back'.

Read the following notes and answer the questions after viewing the programme.

Sickle-cell disease is a disease of the blood that is manifest by the abnormal shapes adopted by the red blood cells. People with the disease suffer from anaemia, major organ damage and death as a consequence of the abnormal red blood cells. The shape of the red blood cells can be explained at the molecular level by a defect in the protein haemoglobin found inside the red blood cells, which in turn can be related to a change in the DNA.

Question 1

The previous paragraph and the programme described a number of *levels of explanation* (Block 4, Section 12) of sickle-cell disease. Identify these levels.

Question 2

Explain how sickle-cell disease illustrates natural selection in action.

The answers to these questions can be found at the end of this booklet.

The high frequency of sickle-cell genes in a population is due to the link between sickle cell disease and malaria. Making the connection between the two diseases is a classic example of 'scientific detective work'. The scientific and medical consequences of understanding both diseases and their social consequences, such as the attempted eradication of

malaria ('A formidable foe') and the screening for sickle-cell disease both in Africa and the USA, illustrate beautifully the interactions between science and society. Screening of babies at birth ensures an early programme of treatment for affected individuals and education of parents and communities in order that they can give support for this treatment. The various world-wide bodies involved in studying and promoting awareness of malaria and sickle-cell disease provide good examples of the need, success and problems of disseminating scientific information.

In Block 9 you will study the molecular basis for inheritance, and this will enhance your understanding of many of the issues related to genetics that are discussed in this programme.

A thread of quicksilver

We recommend that you watch this programme after you have completed studying Block 6. You should read the following notes before watching the programme.

Mercury is an extraordinary substance. It is the only chemical element that is both liquid *and* metallic at room temperature. This programme picks up on the observation, made at the beginning of Block 6 Section 7.2, that 'few substances have made a greater contribution to the growth of scientific understanding than mercury', and looks at just some of the contributions that mercury has made to the creative process.

The story begins at Almaden in Spain, the site of the most famous and productive cinnabar mine in the world. Cinnabar is the principal ore of mercury, and after an introduction to both it and mercury itself, four very different contributions of mercury are considered, each one from a different century:

- the experiments of Torricelli and Pascal, which made the atmosphere more real to us by giving it mass and weight, and founded the science of meteorology;
- the work of Lavoisier and Priestley, which led to an understanding of the nature of combustion and respiration, and laid the foundations of scientific chemistry;
- the discovery of the electric motor by Michael Faraday;
- the discovery of superconductivity by Kamerlingh Onnes.

Of these four items, only the first two play a large part in *Discovering Science*. The work of Torricelli and Pascal is prominent in Section 7 of Block 6, where mercury columns are used extensively to measure gas pressures. The idea that combustion and respiration are chemical reactions with atmospheric oxygen runs right through the course. So does the distinction between chemical elements and chemical compounds, which Lavoisier built into the working language that chemists use. This topic is most directly addressed in Block 6, Sections 4–4.3. However, all four items bring out mercury's unique combination of properties — its great density, its liquidity, its metallic conductivity, its delicately poised combination with oxygen, and its beauty.

Answer the following questions after viewing the programme.

Question 1

Torricelli's experiment suggests that at sea-level, above any area of the Earth's surface, the weight of the atmosphere is balanced by that of a column of mercury about 76 cm high. When two things balance on a set of scales, we assume that their masses are the same, so here we'll assume that the mass of the atmosphere that surrounds the Earth is equal to the mass of an imaginary mercury ocean covering the entire surface of the Earth to a depth of 76 cm.

In Block 3, Section 10, the Earth was modelled as a perfect sphere of radius 6 370 km. Such a sphere has a surface area of 5.10×10^8 km^2. Imagine this surface area of the Earth stretched out flat and covered by a layer of mercury 76.0 cm deep.

(a) Calculate the volume of this mercury ocean in cubic metres.

(b) Use the density of mercury (13.6×10^3 kg m^{-3}) to calculate the mass of the mercury ocean, and hence the mass of the Earth's atmosphere in tonnes (1 tonne = 1 000 kg).

Question 2

Air is a mixture of oxygen with other gases (Block 2, Section 6). When copper, aluminium or iron are heated in air, they react with oxygen to form oxides (see, for example, Block 6, Section 3.2). Mercury will also form an oxide (which is red) when it is heated in air at 300 °C, but the oxide of mercury differs from the oxides of the other three metals in a very important respect when they are heated to about 500 °C. Explain this difference.

The answers to these questions can be found at the end of this booklet.

Uncertain principles

We recommend that you watch this programme after you have completed studying Block 7. You should read the following notes before watching the programme.

The programme explores one of the main ideas of quantum physics that is discussed in Block 7, namely wave–particle duality. It follows the story of the electron: how its particle-like nature was discovered by J. J. Thomson in 1897, and its wave-like nature was demonstrated by his son, George Thomson, thirty years later. Both of these scientists received Nobel prizes for their work and both were correct: the electron behaves like a particle *and* it behaves like a wave.

Another focus of the programme is the Solvay conference of 1927 at which many of the important physicists of the day met to discuss the new ideas of quantum physics (see Figure 1). Most of the scientists you read about in Block 7 were present at this conference, which marked a turning point in the understanding of the quantum world.

As you watch the programme make a note of points that will enable you to answer the following questions.

Figure 1 The people who attended the Solvay conference in 1927. In particular all the people mentioned in Block 7, namely Max Planck, Niels Bohr, Erwin Schrödinger, Werner Heisenberg, Wolfgang Pauli, Albert Einstein, and Louis de Broglie were present, as was Paul Dirac who you will read about in Block 11.

Question 1

(a) Which aspect of the behaviour of electrons is used to explain how vacuum tubes (valves) operate? How did understanding this behaviour help to explain why early amplifiers were not very efficient?

(b) Which additional aspect of the behaviour of electrons is needed to understand the operation of solid state semiconductor devices, such as transistors and microchips? How do electrons behave as they travel through the crystal lattice in such devices?

Question 2

Briefly explain the role of Albert Einstein in the history of quantum physics, as outlined in this TV programme and in Block 7.

The answers to these questions can be found at the end of this booklet.

The birth of liquid crystals

We recommend that you watch this programme during your study of Block 8. You should read the following notes before watching the programme.

This programme concentrates on the development and exploitation of ideas about liquid crystals — the materials that are used in display devices such as digital watches. From a chemical curiosity as a fourth state of matter 100 years ago, liquid crystals have become a major area of research and development for use in displays in electrical devices, temperature monitoring and biological systems. The programme emphasizes the relationship between developments in science and technology, together with the interdisciplinary nature (biology, physics and chemistry) of such product development. It also illustrates the impact that personalities and events can have on the way that science develops.

As you watch the programme make a note of points that will enable you to answer the following questions.

Question 1

What are the important properties of liquid crystals and, in particular, what are the properties that are essential for displays in electrical devices?

Question 2

What are the important features of a liquid crystal molecule, and how were 'ideal' liquid crystalline compounds developed?

The answers to these questions can be found at the end of this booklet.

Hidden visions

We recommend that you watch this programme after you have completed studying Block 8. You should read the following notes before watching the programme.

One of the basic science skills is observation. However, the observations of early scientists were limited to what they could see with their unaided eyes. This programme maps out some of the important stages in the historical development of instruments that allow scientists to look at small objects in detail. It starts with the development of the *optical microscope*, from a simple lens for observing the wonders of nature to a modern scientific tool for observation and classification.

In the late 1800s scientists realized that the size of the smallest detail that could be seen using the optical microscope was limited by the wavelength of light to a few hundred nanometres. This barrier was broken with the discovery of *X-ray diffraction*, a technique that enables scientists to determine the relative positions of the atoms in crystals, and which has led to the development of a field of study now known as X-ray crystallography.

This still leaves a middle ground between the smallest detail visible with the optical microscope (hundreds of nanometres) and the size of atomic and molecular structures (a fraction of a nanometre). This was filled by the *transmission electron microscope*, and later by the *scanning electron microscope*, both of which use a beam of electrons, rather than a beam of light, to produce an image. You can see a variety of such images of cells and components of cells in Block 9. More recently, *scanning tunnelling microscopes* have been used to show the positions of individual atoms on a surface. You have seen such images in Block 6 Figures 1.1 and 15.1 and on the title page of Block 7.

The programme discusses all of these instruments, and it also discusses the relationship between science and art, and how beauty in the images produced by these instruments is in the eye of the beholder.

As you watch the programme make a note of points that will enable you to answer the following questions.

Question 1

(a) Suggest two ways in which an optical microscope and an electron microscope differ in the way they produce an image. (b) Why are electron microscope images not in colour?

Question 2

X-ray crystallography and scanning tunnelling microscopy produce images in fundamentally different ways from optical and electron microscopes. In one or two sentences, outline the principles behind X-ray crystallography and scanning tunnelling microscopy.

The answers to these questions can be found at the end of this booklet.

Lifelines

We recommend that you watch this programme after you have completed studying Block 9. You should read the following notes before watching the programme.

Our current understanding of inheritance has been built up from a synthesis of the work of a large number of scientists over the last 150 years or so. Three of the important early contributors were:

- Darwin, with his theory of natural selection, which you have studied in Sections 9–11 of Block 4 and Sections 13 and 14 of Block 9, including the Galapagos CD-ROM activities;
- Mendel, with his breeding experiments, which are discussed in Sections 8 and 9 of Block 9;
- Miescher, who discovered DNA, which is the key to inheritance, as you have discovered when studying Section 3 of Block 4 and Sections 10 and 11 of Block 9.

This programme looks at the key contributions that these three scientists made to the development of our understanding of inheritance. It links together many of the concepts that you have studied in Blocks 4 and 9, it shows the scientific context in which these scientists worked, and it provides a perfect illustration of the way that scientific ideas evolve.

As you watch the programme, try to answer the following question.

Question 1

What was the immediate consequence for Darwin's theory of evolution of the re-discovery in 1900 of Mendel's work?

The answer to this question can be found at the end of this booklet.

Read the following notes after viewing the programme.

Charles Darwin's theory of natural selection depends on four propositions, set out in Section 10 of Block 4. Darwin had collected evidence that all four operated in nature, but for the fourth, the principle of inheritance, he had no idea what the mechanism was.

One of the ironies of history is that just two years before the publication of Darwin's book on the origin of species, Gregor Mendel, a priest attached to the Abbey of St. Thomas at Brno in what is now the Czech Republic, started a series of experiments. The results that he obtained were to provide an explanation of the mechanism of inheritance.

The significance of Mendel's experiments was not appreciated until his work was re-discovered in 1900. There is an obvious question to ask. Did Darwin and Mendel know of each other's work? The answer seems to be that Darwin never met Mendel and had probably never heard of him. Mendel, however, visited London for the Great Exhibition in 1862, as a member of a party of around 100 tourists and, amongst his books, was a German edition of *The Origin of Species*, published in the same year.

Gregor Mendel did not understand all the factors that governed inheritance. He did not postulate that real, material particles combined together to produce the inherited characters that he observed. Indeed, as the famous geneticist T. H. Morgan wrote some 50 years later: 'For all we know to the contrary, the good abbot may have had something more spiritual or mystical in mind.'

It is a further irony of history that, while Mendel was experimenting with his pea plants, in Tubingen the Swiss biochemist, Johann Friedrich Miescher, was

isolating nucleic acids from pus cells. Miescher was working with DNA, the molecule that carries inherited information encoded within its structure. It wasn't until 1953 that the significance of DNA became apparent and the probable nature of its chemical coding was revealed. However, in a letter that Miescher wrote to his uncle in 1892, he revealed a surprising understanding of the potential of his work, though the letter remained unknown until the 1960s. In the letter he speculated that

> ... the many asymmetric carbon atoms provide a colossal amount of ... isomerism. In them all the wealth and variety of hereditary transmissions can find expression, just as all the words and concepts of all languages can find expression in twenty-four to thirty alphabetic letters.

History, as the TV programme says, would mark Dr Miescher as a rather clever man.

Lost worlds

We recommend that you watch this programme any time after you have completed Block 10, Section 3. You should read the following notes before watching the programme.

This programme looks mainly at aspects of extinction as seen in the fossil record. Despite being the fate of most species, extinction was not accepted as a fact of life until the early 19th century. The acceptance of extinction is described in the programme as a 'huge conceptual shift'.

Geology in the 19th century was at the cutting edge of science, and its place then is likened to that of cosmology today. Scientists gradually became aware that the fossil record was far older and richer than previously thought, and that it could provide a huge amount of information about the history of the Earth and the course of life through time.

Although the awareness of the fact of extinction, and of the immense age of the Earth ('deep time'), were both major advances in scientific understanding, they were not sudden leaps following one particular observation or experiment. Each of these crucially important concepts took a long time to become established as the tide of evidence came slowly in. The programme concludes with a warning derived from a more recent tide of evidence.

As you watch the programme, make a note of points that will enable you to answer the following questions.

Question 1

According to the programme, why did many people at the start of the 19th century find it impossible to accept the accumulating evidence that some fossils were the remains of *extinct* species?

Question 2

To whom do the following descriptions apply? Note that some extra information is given here beyond that given in the programme.

(a) A brilliant Frenchman who lived from 1769 to 1832, he is widely regarded as founding the two sciences of comparative anatomy and palaeontology. About 1800, he argued that the many different fossil bones and teeth that were similar to, but different from, the bones and teeth of large modern animals (such as elephants) must belong to *extinct* species; the animals from which these fossils came would simply be too conspicuous to have been overlooked by travellers throughout the world. From his work in the Paris area, he concluded that there had been a series of catastrophes that had swept away whole living populations, and that such catastrophes were a common feature in Earth's history.

(b) A Scottish geologist, originally a lawyer, who lived from 1797 to 1875. His treatise *Principles of Geology* (1830–1833) was highly influential, being read, for example, by Darwin during his voyage on the *Beagle*. (See also Block 10, Section 8.2.) He vigorously opposed the ideas of catastrophism, promoting the idea that 'The present is the key to the past', and argued that the Earth was very much older than the 6 000 years many then believed it to be.

Question 3

Apart from numerous problems caused by the incompleteness of the fossil record and the geological record in general, why is it so difficult to establish the causes of extinctions?

Question 4

According to the programme, why did mammoths become extinct?

The answers to these questions can be found at the end of this booklet

Making contact

We recommend that you watch this programme after you have completed studying Block 12. You should read the following notes before watching the programme.

This programme is about the search for extraterrestrial intelligence, a topic which was mentioned only briefly in Section 4.2.2 of Block 12 'Life in the Universe'. Travel to the stars is not a practical way to find extraterrestrial intelligence (ETI), so some other strategy must be used, and listening for extraterrestrial radio signals is a good one. Listening started in 1960, and, so far, no ETI signals have definitely been detected. However, the search has barely begun. The programme concentrates on these radio searches, and includes extensive contributions from the leading figures in this expanding field of enquiry. Towards the end of the programme, the Drake equation is introduced. This is an equation for the number of extraterrestrial civilizations in our Galaxy today that are attempting interstellar communication. But can we obtain a reliable value for this number from the equation?

As you watch the programme, make a note of points that will enable you to answer the following questions.

Question 1

In one sentence, state why is it impractical to search for ETI by travelling to other stars.

Question 2

What was the 'Wow!' signal?

Question 3

Why is any value obtained from the Drake equation no more than guesswork?

The answers to these questions can be found at the end of this booklet.

Answers to questions in programme notes

The science of climate

Question 1

(a) The programme discusses:

- human measurements of temperature with thermometers over the past few hundred years;
- tree ring measurements (dendroclimatology);
- measurements of ocean sediments;
- measurements of CO_2 in Antarctic ice cores.

(b) Evidence from tree rings and ocean sediments is not discussed in the book. Each tree ring corresponds to the growth of the tree in a particular year, which depends on climatic conditions. Measurements of the rings provide information about such things as temperature, rainfall, sunshine, etc., though measurements on different trees are required to piece together all this information. Live trees provide information about climate over the last few hundred years, but the record can be extended back for thousands of years using 'dead' wood from buildings, for example.

The type of ocean sediment provides information about the climate when it was deposited; red clays were deposited in glacial periods from material weathered and eroded from the land, and white carbonate deposits were laid down in interglacial periods. These carbonate deposits are the remains of plankton, and they provide information in a similar way to the pollen samples collected from peat bogs or sediments in lakes. Different types of plankton thrive in different temperature conditions, so by examining the assemblage of plankton obtained from a given depth of the sediment, deposited at a particular time, scientists can deduce the temperature of the surface ocean at that time. Ocean sediments allow scientists to extend the climate record back to half a million years ago.

Question 2

The climate model overestimated the change in global mean surface temperature over the past century because it did not include the effects of sulfur dioxide emissions due to human activities. These emissions lead to production of sulfate aerosols, which reflect the incoming solar radiation, thus leading to a reduction in the Earth's surface temperature. Also, the aerosols cause condensation of water vapour to produce clouds, and the type of clouds produced by aerosols leads to surface cooling of the Earth. When these effects are incorporated into the climate model, the agreement with the measured temperature changes over the past century is much better.

{Note that this is an example of the scientific method in action. Scientists developed a climate model that included a range of different factors and that was based on many observations and measurements, and they ran the model to produce a prediction for the temperature change over the past 100 years. They found that it overestimated the temperature change, so they refined the model to include effects of sulfur dioxide emissions. The revised model made a much better prediction. However, they stressed the limitations of theories and models of climate. There is still much that we do not know about the causes of climate change. Continuing interdisciplinary research will progressively refine the models, but we can never hope to construct a complete model that will account for all of the detailed changes in the complex system responsible for the Earth's climate.}

A formidable foe

Question 1

The stages in the *Plasmodium* life cycle that take place in humans involve the organism multiplying by asexual reproduction (mitosis). The feeding mosquito injects *Plasmodium* sporozoites into the human bloodstream, which reach the liver and multiply by mitosis (one sporozoite becomes about 40 000 in 5–6 days). These are then released into the bloodstream as merozoites. The merozoites enter red blood cells where they reproduce, again by mitosis, increasing tenfold in 48 hours.

Once taken up by an *Anopheles* mosquito in a blood meal, the *Plasmodium* life cycle switches to sexual reproduction. Gametocytes produce gametes by the process of meiosis, and fertilization within the mosquito's gut results in the production of zygotes. The zygotes then pass through the gut wall and form oocysts in the thoracic cavity. Each oocyst releases about 1 000 sporozoites which travel to the mosquito's salivary gland, from where they can be injected into a human, enabling the life cycle to begin anew.

Question 2

A sketch of the life cycle of *Plasmodium* is shown in Figure 2.

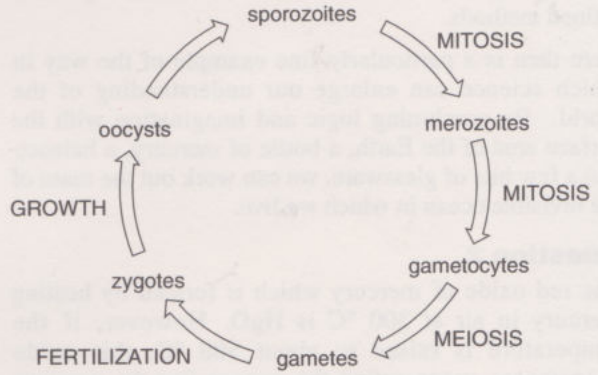

Figure 2 The life cycle of *Plasmodium*.

Sickle-cell disease: a lethal advantage

Question 1

Sickle-cell disease is a disease that affects certain *individuals*. However, such individuals are members of a *community* or *population* that provides care of affected individuals.

The shape of the red blood cells can be explained by a defective haemoglobin molecule, which in turn is related to a change in the DNA — an explanation at the *molecular* level.

Question 2

Sickle-cell disease has a genetic basis, and its presence in a population can be linked to differences in survival and fertility among individuals in the populaton. These differences result in natural selection.

A thread of quicksilver

Question 1

(a) The volume of the mercury ocean is equal to its surface area multiplied by the depth. First we convert these quantities into square metres and metres, respectively (the basic SI units for area and length). Since 1 km = 10^3 m,

$$1\ \text{km}^2 = 10^3\ \text{m} \times 10^3\ \text{m} = 10^6\ \text{m}^2$$

So

$$\text{area of mercury ocean} = 5.10 \times 10^8\ \text{km}^2$$
$$= 5.10 \times 10^8 \times 10^6\ \text{m}^2$$
$$= 5.10 \times 10^{14}\ \text{m}^2$$

The depth of the mercury is 76.0 cm or 0.760 m, since 1 cm = 10^{-2} m. Thus,

$$\text{volume of mercury ocean} = 5.10 \times 10^{14}\ \text{m}^2 \times 0.760\ \text{m}$$
$$= 3.88 \times 10^{14}\ \text{m}^3$$

(b) Because density = mass/volume, mass = density × volume, and so

$$\text{mass of mercury ocean} = 13.6 \times 10^3\ \text{kg m}^{-3} \times 3.88 \times 10^{14}\ \text{m}^3$$
$$= 5.27 \times 10^{18}\ \text{kg}$$
$$= 5.27 \times 10^{15}\ \text{tonnes}$$

since 1 kg = 10^{-3} tonnes. So the mass of the Earth's atmosphere is about five thousand million million tonnes, which is close to values calculated by more refined methods.

Here then is a particularly fine example of the way in which science can enlarge our understanding of the world. By combining logic and imagination with the surface area of the Earth, a bottle of mercury, a balance and a few bits of glassware, we can work out the mass of the invisible ocean in which we live.

Question 2

The red oxide of mercury which is formed by heating mercury in air at 300 °C is HgO. However, if the temperature is raised to about 500 °C, this oxide decomposes, regenerating the oxygen that the mercury originally extracted from the air, but in a pure form.

$$2\text{HgO(s)} \longrightarrow 2\text{Hg(l)} + \text{O}_2\text{(g)}$$

It was this reaction that Priestley and Lavoisier used to extract oxygen from air. Strong heating of the other three oxides does not produce a change of this kind.

Uncertain principles

Question 1

(a) The behaviour of vacuum tubes relies on the fact that electrons can behave as particles. Since the early amplifiers did not have a very good vacuum inside the glass tube, the electrons were impeded by colliding with atoms as they travelled from one part of the device to another. By improving the vacuum, the passage of electrons was made easier and greater amplification was achieved.

(b) The properties of semiconductors rely on the fact that electrons can also behave as waves. As electrons travel through a crystal lattice, they are diffracted (spread out) in the same way that a water wave spreads around obstacles. So in one sense electron waves interact with the whole crystal structure at the same time: the electron can be found anywhere in the semiconductor.

Question 2

Albert Einstein proposed that light only exists in discrete amounts (quanta), and these were later named photons. He also had a hand in gaining acceptance for de Broglie's ideas that electrons can behave as waves. However, he later came to dislike many of the implications of quantum physics. He could not accept that the outcome of a quantum process was governed by chance and probability. He desperately hoped he would find a way of enabling the outcomes of individual quantum processes to be predicted with absolute certainty. He was not successful in this, and it is now believed that such indeterminacy lies at the heart of all quantum processes.

The birth of liquid crystals

Question 1

The programme started by explaining that liquid crystals are pure compounds that have more than one melting temperature. The compounds shown melted initially to give a cloudy state and were then converted at a higher temperature into a clear liquid. The molecules of liquid crystalline compounds are rod shaped, and in the solid state they exist in ordered arrays. On heating, the molecules start to move around, just like a liquid, but because of their rod-like shape they are ordered — they all remain aligned. This is the cloudy, liquid crystal, state. After further heating this order is eventually lost and a normal liquid is obtained.

Liquid crystals rotate the plane of plane-polarized light; the extent of rotation depends on the temperature.

The alignment of the molecules in liquid crystalline compounds used for electrical devices can be controlled by applying electric voltages.

For display devices, the compounds need to have a low melting temperature, to be chemically stable, to remain in the liquid crystalline phase between –20 °C and 60 °C, to withstand a high vacuum, to have a low viscosity, and to respond rapidly to electrical voltages applied to align the molecules.

Question 2

The important feature of a liquid crystalline molecule is that it has shape and, in particular, that it is rod shaped. The rod-shaped compounds developed by Professor Gray had two connected ring systems and a long tail. These compounds were optimised by preparing a series of compounds where only one feature was altered, and then comparing the liquid crystal properties of this series of compounds. In this way, rules were developed for predicting which type of molecule would exhibit ideal liquid crystal properties. For example, when the length of the tail was increased systematically one carbon atom at a time, the resulting compounds changed from being solids at room temperature to becoming liquid crystals.

Hidden visions

Question 1

(a) Differences between optical and electron microscopes include:

(i) An optical microscope uses light to produce an image of an object, whereas an electron microscope uses a beam of electrons.

(ii) An optical microscope uses glass lenses to focus the light, whereas an electron microscope uses electric and magnetic forces to focus the beam of electrons.

(iii) Optical microscopes can be used to observe an untreated object in the air, whereas with an electron microscope the object is in a vacuum, and with a scanning electron microscope the object must first be covered with a metallic film.

(b) Objects appear to be coloured because they absorb and reflect light of different wavelengths to different extents, and because our eyes and brains perceive different wavelengths as different colours. Beams of electrons also behave as waves (Block 7 Section 10.2), though their wavelengths are generally much shorter than those of visible light. However, the fluorescent screens used to detect the electrons and form an image in an electron microscope respond to all wavelengths of electrons in a similar way, and so a monochrome image is obtained, based solely upon the intensity of the electron beam.

Question 2

X-ray crystallography depends upon the diffraction of X-rays by the regular array of atoms in a crystal. The intensities and positions of the spots in the diffraction pattern enable the positions of the various atoms to be calculated.

In scanning tunnelling microscopy, a tiny probe scans the surface, essentially 'feeling' the surface of the object, and detecting the positions of protruding atoms.

Lifelines

Question 1

The immediate consequence of the re-discovery of Mendel's work was that it was seen as an alternative, and better, explanation for evolution than Darwin's. {In fact, it took until the middle of the 1930s and two influential books, Dobzhansky's 'Genetics and the Origin of Species' and Julian Huxley's 'Evolution: the Modern Synthesis', for most scientists to accept that Mendel's work *underpinned* Darwin's theory of evolution by natural selection.}

Lost worlds

Question 1

Many people could not reconcile the idea of extinction with the religious view of a natural world planned and made perfect by God.

Question 2

(a) Georges Cuvier; (b) Charles Lyell.

Question 3

There are always some environmental changes taking place, and the way that the various Earth systems are linked together is immensely complex. The evidence during mass extinctions often points to several environmental factors acting together. However, merely showing that certain events were correlated in time during extinctions is very different from establishing the full chain of cause and effect: as the programme demonstrates, establishing this is very difficult, even for more recent extinctions such as that of the mammoth.

Question 4

It is likely that climate change or human hunting or, quite probably, a combination of both, were responsible for the extinction of mammoths. It is, however, impossible to ascertain which of these two factors was more important. About 15 000 to 10 000 years ago, climate change (global warming) caused a change in vegetation and, at the same time, hunting increased as, for example, when North America was colonized by humans. Modelling shows that only a small increase in the percentage of mammoths killed by humans could have rapidly led to a terminal decline in mammoth populations.

Making contact

Question 1

It is impractical to travel to the stars because their enormous distances from us mean that it would take thousands of years to reach even the closest star. {We lack the Star Trek technology that would allow us to travel faster than the speed of light!}

Question 2

The 'Wow!' signal was a large, short-lived signal detected by the radiotelescope Big Ear in Ohio in 1977. It was never heard again, and though it was {probably} extraterrestrial, its origin remains a mystery. {Big Ear was demolished in 1998 to make way for a golf course.}

Question 3

Several factors in the Drake equation are unknown. These include

- the probability that life will evolve to give intelligent species
- the duration (if any) of the time for which any technological civilization attempts interstellar communication.

Estimating values for these factors from our knowledge of evolution and technological development on Earth involves huge uncertainties, so the number derived from the Drake equation will be little more than a (possibly inspired) guess.

{The reasons were not stated in these terms in the programme, but these formulations can be deduced from what was said in the programme.}

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